An Investigation Into The Geomorphology Of The Ohio Caverns

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Abstract

The Ohio Caverns are located in north west Champaign County about four miles east of the town of West Liberty, Ohio on Route 245. The caverns are perhaps the most extensive in the entire state. The caverns wind through the rock in a particular configuration. This paper attempts to establish a relationship between this configuration and the joint patterns in the area. The caverns also have a particular internal configuration. This paper also attempts demonstrate how this internal configuration is a function of various geologic processes. It becomes involved in a consideration of the origin of the debris in the cave and the effects the debris had on the formation of the cave. It considers the effects the water table had on the cave as the water table retreated. This report also deals with present processes going on in the cave and attempts to relate them to the local geology.

Introduction

Like many other limestone caverns, the Ohio Caverns were formed along joints in the rock by dissolution according to the equation:

$$CaCO_3 + H^+ \longrightarrow Ca^{++} + HCO_3^-$$

Many other processes are involved with this one in the creation of limestone caverns. The determination of the particular variations involved in the formation of the Ohio Caverns was the object of this research and is the subject of this paper.

Background and History

The Ohio Caverns occur within a hill of Columbus limestone[1] called Mt. Tabor. Mt. Tabor is located in north west Champaign County; SW¼, SE¼, R.13N., T.5E., Kingscreek Quadrangle (Sheet 1). To the north east there is a long ridge of glacial moraine[2]. To the west is the Mad River valley[3]. The drainage off the north part of Mt. Tabor, where the Ohio Caverns are located, is essentially radial. The valley to the east drains to the south east and the area to the immediate west drains to the west and south west. Here the Columbus limestone is capped by Ohio shale[4] the thickness of which varies due to erosion. The limestone exhibits variation in color, texture, and grain size and has undergone varying degrees of dolomitization and silicification. There are numerous lenses containing chert nodules (3 in. to 12 in.) throughout. The area above the caverns is strewn with glacial erratics and exhibits one outcrop of Ohio shale (Sheet 1).

The cave is in a vaguely H shape (Sheet 2). The respective arms are referred to as the north, south, east, west and unmapped arms and are so noted (Sheet 2). It is evident that at the location first Y, the elevation of the east arm is below the elevation of the north and west arms. Similarly, it is evident that at the southern room on the south arm has a higher elevation than the rest of the south arm adjacent to it. Despite this the cave is essentially level. Before the cave was open to tourists it was partially filled with mud and soil like debris. With few exceptions the debris has been removed entirely or displaced to other locations within the cave. What are left are debris contours along some of the walls. The debris was removed through the original entrance (OE on Sheet 2) and through the service shaft (SS on Sheet 2) and spread across the surface at these places.

There is a second level to the cave; there being two passages (noted on Sheet 2) that have been cleared to it. The second level is no where near as extensive as the first and most of it is filled with debris. There are at least four other places that are covered with water from time to time and/or show signs of sinking. These sink and/or drain to somewhere below. The speculation is that the drainage either passes through a sort of sealed off area within the second level, since the observable places on the second level are always dry, or that it goes to a third level that lies within the water table at this time.

The cave has varying types of speleothems present in it. They consist of stalactites, soda straw stalagtites, stalagmites, helectites and draperies.

They are composed primarily of limonite and caldite. There are speleothems that are composed of calcite and limonite growing intertwined with each other. These are very unusual in that the calcite is snowy white thus indicating there is no limonite contaminating it. There are coatings of calcite, travertine, limonite, and pyrolusite on the walls throughout. Most speleothems have been stripped out of the east and west arms but the north and particularly the south arms contain large numbers of them.

The caverns were discovered in August 1897 by a farm boy who observed a pool of rain water draining rather quickly. He returned with a shovel and uncovered the entrance to the cave. The other openings that have been made into the cave are entirely artificial.

Research

The research that went into this paper consisted of the following:

1. The construction of a map
2. The collection of rock and debris samples for analysis under a hand lens and by X-ray diffraction,
3. The construction of cross sections of selected areas,
4. The collection of joint orientations for analysis on the Wulff net and on histograms.
5. The collection of pH readings,
6. The plotting of rock fall areas on the map,
7. The making of other assorted observations.

Procedure and Results

In order that evidence could be presented more easily it was necessary to acquire a map of the caverns. The only other map that existed until this time (Dec. 1970) was made in 1916 by Thomas M. Hills[5] and his associates. Other portions of the cave were discovered after 1916 and thus it was necessary to make a new map.

A Brunton compass and a one hundred foot tape were used. First, the four openings to the dave were plotted by measuring distances and bearings above ground. Then, the same thing was done underground. The passages were sketched in by estimating their widths and side alcolves were plotted in similarly according to their positions along the tape.

Both maps have inaccuracies. Mr. Hills' map claims a distance of 1350 Ft. between Pe (present entrance) and OE (old entrance). Having measured this distance on the surgace it was found to be approximately 1000 Ft. The same distance when considered from underground came out to be no more than 1125 Ft. It seems that when the distance was plotted from OE to the first Y and from PE to the first Y (see Sheet 2) there was an overlap of 125 Ft. This was resolved by choosing a point inbetween for the first Y and fudging the two ends together on tracing paper. Similarly when the east and south arms were plotted on there were respective differences of 50 and 75 feet. As a result the map serves in a general way in locating reference points underground. It should not be used to make correlations between surface and subsurface points.

At two points on the map arrows are shown pointing into space. The arrow on the north arm points into a passage of moderate extent which was not mapped because of a time shortage. The arrow on the south arm points into an extensive arm which is reputed to require a four hour crawl, Through the mud, to complete a round trip of it. It was not mapped because of the time shortage.

On the south arm there is a dashed-in area representing the extent of a large room. It was drawn under the supervision of Max Egans who has been back into it. I did not go vack there because of the time problem and because the cave is a commercial operation and one would have to crawl among the formations thus jeopardizing them. At the rear (north end) of this room there is a rock fall. The speculation is that this is the same rock fall dashed-in on the west arm since they are so close together on the map.

The rock samples 111 through 123 were first analyzed under a hand lens. The results are listed in Table 1.

Table 1.

Sample	Description
111	Shale, yellow-grey, poorly cemented, finely laminated, little carbonate present, well sorted.
112	Limestone, sparry allochemical, very fine grained, homogeneous, well cemented, grey, dirty, minor silicification.
113	Limestone, sparry allochemical, microgranular, homogeneous, well cemented, yellow-grey, very dirty, dolomitized.
114	Limestone, sparry allochemical, very fine grained, homogeneous, well cemented, grey, dirty, dolomitized.
115	Limestone, sparry allochemical, fine grained, homogeneous, well cemented, yellow-grey, very dirty, minor silicification.
116	Limestone, sparry allochemical, microgranular, yellow-grey, homogeneous, partially weathered, dirty minor silicification.
117	Chert, thoroughly weathered, homogeneous, white, minor carbonate present.
118	Limestone, sparry allochemical, grey-brown, fine grained, homogeneous, well cemented.
119	Limestone, sparry allochemical, grey-brown, fine grained, homogeneous, well cemented, dirty.
120	Limestone, sparry allochemical, fine grained, homogeneous, moderately well cemented, grey, dirty.
121	Limestone, sparry allochemical, very fine grained, homogeneous, well cemented, grey, dirty.
122	Limestone, sparry allochemical, fine grained, homogeneous, well cemented, grey.
123	Limestone, sparry allochemical, very fine grained, homogeneous, well cemented, brown.

All rock samples are located on the map (Sheet 2). Debris samples AAA through AAG are located on Sheet 2 whereas samples AAK-A and AAL-B are located on Sheet 1. Samples AAK-A and AAL-B were taken on the surface with a 16 In. soil probe, near enough to the old entrance to be representative, but far enough away so as not to include any debris from the cave.

Samples 111 through 117 were first washed with water, then ground up and dissolved in hydrochloric acid. The solution was filtered and the filter paper was dried. The insoluble residue was scrapped off and sifted through a 200 mesh screen.

All debris and soil samples were first dried, then ground up in a mortar and pestle and then coned and quartered until a manageable portion remained. The material was then sifted through a 200 mesh screen.

The samples were mounted on glass slides with Duco Cement and acetone. They were scanned for angles of two theta between 5 and 50 degrees. Copper K alpha radiation was used with a Nickel filter and a 3 degree Solerslit. Full scale deflection was set at 2000 and both gear drives were set in high.

Two or three peaks were taken as evidence for the presence of a mineral while one good one was only considered as a possibility. The diffraction patterns were analyzed for the presence of the following minerals:

1. Calcite
2. Dolomite
3. Aragonite
4. Quartz
5. Feldspar
6. Illite
7. Kaolinite

Figure 2 is a statement of the results obtained from the X-ray analysis. An X denotes the presence of a mineral while a ? denotes only the possibility of its presence.

(Table 2)

	Calcite	Dolomite	Aragonite	Quartz	Feldspar	Illite	Kaolinite
111				X			
112				X			
113				X			
114				X			
115				X			
116				X			
117	X			X			
AAA		X		X			
AAB		?		X			
AAC		?		X	?		
AAD		X		X			
AAE		?		X	?		
AAF		X		X			
AAG		?		X			
AAK-A				X	X		
AAL-B				X	X		

The pH readings were taken with Phenaphthazine paper. It was possible to make distinctions of only 0.5 units of pH. The readings obtained ranged from 4.5 to 5.5 and are displayed on Sheet 2.

The orientations of the joints measured in the cave were recorded on two different bases There is one non-random set of data that was compiled by observing and recording the orientations of those joints involved in the formation of passages. There is another random set of data that was compiled by selecting random locations about the cave and by observing and recording the orientations of all the joints at these locations. Points J1 through J10 (Sheet 2) are the points where random data were collected. Table 3 is a list of all the orientations measured.

All the orientations were plotted on a Wulff net (Composite Sheet). Any joint involved in the formation of a passage, regardless of whether or not it was selected randomly or non-randomly, has its pole shown as a red dot. All other joints are displayed as green dots.

Table 3

Location	Random joint orientations Strike	Dip	
J1	N85W	80N	
	N60E	90	
	N50E	90	Passage
	N85E	80S	
	N80W	80N	
J2	N70W	90	Passage
	N30E	90	
	N70E	90	
	N35E	85N	
	N41E	90	
	N80E	90	
	N10E	90	
J3	N85E	90	
	N10E	90	
	N15W	80W	
	N 8E	90	
	N75E	90	Passage
J4	N40E	90	Passage
	N 8W	90	Passage
	N77E	90	
	N20W	90	
J5	N12W	90	Passage
	N67W	90	
	N73E	90	
	N33E	90	
	N26W	90	
J6	N79E	90	Passage
	N30E	83E	
	N28E	90	
	N82E	78S	
	N15W	90	
J7	N 7W	90	Passage
	N20E	90	
	N87E	90	
	N70E	85N	
	N73E	90	
J8	N13W	90	Passage
	N18E	90	Passage
	N47W	90	
	N75E	90	
	N80E	90	

Location	Random joint orientations Strike	Dip	
J9	N30E	90	Passage
	N55W	90	
	N 5E	90	
	N90	90	
J10	N73E	90	Passage
	N35E	80S	
	N10W	90	
	N65E	90	
	N30E	90	
	N45E	90	

Orientations of the non-random passage forming joints.

Strike	Dip	Strike	Dip
N 8E	78E	N67W	90
N15E	90	N18E	90
N85W	90	N77W	90
N28E	90	N20W	90
N63W	90	N10W	90
N35E	90	N10W	90
N77W	90	N17W	90
N75W	90	N15W	90
N10W	90	N17W	90
N30E	90	N10W	90
N67W	90	N63E	90
N15E	90	N15W	90
N 4W	90	N74W	90
N28E	90	0	90
N83W	90	N80W	90
N77E	90	N65E	90
N20W	90	N15W	90
N60E	90	N15W	90
N80W	90	N89E	90

Next a histogram (First Histogram Sheet) was compiled. It was observed that all orientations had dips of 90 or nearly 90 degrees. The dips were ignored and the orientations were plotted. The histogram consists of a one hundred and eighty degree spread, divided into five degree increments, with the number of strike measurements within each increment plotted as the height of the column. The same thing is done for points J1 through J10 except that the height of the column is replaced by an x if any strike falls within the increment. Points J1 through J10 are displayed with a geographic preference.

Another histogram (Second Histogram Sheet) was compiled. The same histogram that showed the numbers of strikes with respect to five degree increments of strike is shown again but this time with a different histogram. All passages and rooms with widths that were at least 15 feet were also measured for length and bearing. The results are shown as a histogram of area with respect to particular bearings. The same one hundred and eighty degree spread with five degree increments was used.

There are also horizontal and/or bedding joints through out the cave but these are not treated here.

Interpretation of Results

There two possible major variations in the formation of a limestone cavern by dissolution. Either a stream flowed through the cavern during its formation or it was formed by an underground lake. It is unlikely that a stream formed the Ohio Caverns since the north, south, east, and unmapped arms all end in natural terminations. The fact that there was an unruptured soil covering over OE suggests that no stream had ever passed that way.

If a stream had passed into the caverns through OE it would have carried material from outside into the caverns. The fact that the soil on the outside contains feldspar (Table 1) and the debris on the inside exhibits no conclusive evidence that it contains any suggests that no material was introduced from the outside. Sample AAA was retrieved very close to OE but it had no feldspar in it. This is conclusive evidence that the caverns were formed by a lake type environment.

In considering the Geomorphology involved in the creation of particular cross sections, it is obvious that resistant beds are a major potential influence. The obvious suggestion would be that the lenses containing chert nodules are resistant beds but this is not so. There are places where the chert nodule lenses come very close to coinciding with the ceiling but this is mere coincidence. There are other places where eight of nine chert nodule lenses dan be counted on a single plane wall. Resistant beds should protrude. It is certainly true that the nodules protrude but always the adjacent rock is dissolved back into coincidence with the wall.

Besides resistant beds, there are three other potential major influences involved in the creation of a particular cross section. The first is a reposed water table[6]. For a given water table dissolution will proceed within the water table but not above it. The result is a ceiling like the on in CS1 (See Cross Section Sheets). Samples 120 and 121 were collected at this place. There is little in their descriptions to indicate that a radical difference in solubility should exist. When etched with hydrochloric acid the samples exhibited very similar reaction rates. The grose differences in dissolution can only be explained by a reposed water table.

Often times the debris on the floor of a cave serves to protect the rock below it from dissolution. This process results in the production of a V-shaped passage[7]. There is a theory, yet to be demonstrated, that V-shaped passages can be produced by dissolution in a density gradient. It is proposed that the bicarbonate ion , because of its greater density, would accumulate toward the bottom of a passage. This accumulation would retard the ability of the solution to dissolve limestone. In effect the rate of dissolution at the top would be greater than the rate at the bottom thus a V-shaped passage would be created[8].

Consider cross sections CS1 and CS2. These two are in close proximity on the map (Sheet 2). Notice that CS2 has a stepped configuration while CS1 does not. If a density gradient were involved both cross sections would have similar configurations. The proximity of the two precludes the possibility that resistant beds are involved in one place and not the other. These configurations can only be accounted for by a debris covering on the floor protecting it from dissolution.

Cross section CS7 shows former debris horizons on the walls. The rate of dissolution below the horizon should have been less than the rate above it. This configuration with the debris can only be explained by having the passage form at one time and then have the debris introduced at a later time. This establishes that, at least at this location, the debris was moble at some time in the past.

At CS5 the rock samples 122 and 123 were taken. There is nothing in their descriptions to indicate radically different solubilities. Etching with hydrochloric acid revealed very similar rates of reaction. The configuration can be accounted for by dissolution at the intersection of a vertical and horizontal joint. But there is CS4 to consider which exhibits an inverted staircase configuration. The two cross sections are in close proximity and thus it is unlikely that resistant beds are involved at one location and not the other. The presence of the deep depression in CS5 and not at CS4 can best be explained by noting that a passage enters at CS5 thus contributing to the dissolution at that point. The inverted staircase effect can be accounted for by a progressive removal of debris cover but the intervals between cycles of removal would have to be progressively greater. Very fine horizons are cut into the wall. These are very straight and very even. Other debris horizons in the cave are not nearly so even thus these can best be explained by etching by a water table. A water table that was obviously so calm could hardly have had currents strong enough to remove the amount of debris indicated. Thus these confugurations must be explained by a progressively lowered water table.

The debris horizons in the Ohio Caverns often exhibit several feet of relief. The situation at CS3 demonstrates this very effectively. Actually CS3 is more of an orthographic projection than a true cross section. The question remains as to why the debtis horizons are irregular. It is within the limits of observable evidence to consider that some irregularities are caused by sinking into the second level. Perhaps the irregularities are due to swirling effects inside currents created when large blocks of rock fell from the ceiling into the lake. Perhaps the irregularities are due to blocks of rock that have fallen, been covered with debris, and presently protrude as humps. Perhaps there is differential compaction caused by water dropping from the ceiling thus causing removal and concentration of smaller particles lower in the debris. No conclusion is possible, with respect to this problem, from the data collected for this research.

In CS6 there was solution along a horizontal joint which was truncated by a vertical joint. Notice that the debris horizon is higher than the stalagtites and stalagmites. The speculation is that the fall block caused material to be ejected out from under it to form the bulge.

Samples 118 and 119 were retrieved in the hope of making solubility correlations. The area of CS6 is covered with deposits and thus the samples had to be taken some distance away. Any correlation between the samples and this point is subject to doubt.

There is nothing in the descriptions of the samples to indicate a radical difference in solubility. Etching with hydrochloric acid revealed very similar reaction rates. If the samples are representative then it is evident that there is a reposed water table involved here. The evidence is inconclusive as to the origin of the two protrusions above the debris horizon. They may have originated because of a solution gradient or because of protection by debris.

From the evidence provided on the Wulff net it is evident that there are at least three and possibly four or more systems of joints in the area of the cave. At least as a whole there are no differences between those joints that form passages and those that don't. However when one considers the first histogram it is evident that, within the limits of the data, there seems to be an omission of dissolution along certain joints in certain areas. More data is needed before any valid conclusions can be drawn.

From the second histogram it is evident that there is only a partial relationship between area and the most frequently dissolved joints. If the two highest columns are considered there is only a difference of ten degreees between them. This could conceivably be a correlation between them. Several of the other peaks are too far away to be correlated with each other. One reason for this is that large parts of the areas involved are due dissolution along horizontal joints and not the vertical ones dealt with by the histogram.

The pH readings were taken with pH paper with a range of 4.5 to 7.5. The readings range between 4.5 and 5.5. This spread is consistent with the lower pH limit of 4 for natural environments[9].

The pH is a reflection of the ability of the soil and rock above the cave to produce carbonic and other acids. In this case the soil is the thinnest at those places closest to the surface, namely at the edges of the hill.

The Ohio shale is well known for its pyrite content. The pyrite oxidizes to form iron oxides and hydroxides as well as sulfuric acid. The limonite speleothems in the caverns probably originated from this process. Thus the thicker the Ohio shale is the lower the pH will be and it is thinnest at the edges of the hill where the cave is very close to the surface.

Another parameter is introduced when one considers that calcium carbonate is the salt of a strong base and a weak acid. The common ion effect ties up of hydrogen ions thus reducing the pH. The pH in the cave becomes a function of the ability of the soil and the Ohio shale to reduce pH and the ability of the Columbus limestone to increase them. Unfortunately the thicknesses of the formations over the cave is not known. It is thus obvious that the thicker the Columbus limestone is the higher the pH will be.

The depths, relative to the surface, are plotted with respect to the pH at the four openings where the thicknesses of rock are known in Table 4.

Table 4

Location	Depth	pH
OE	20 Ft.	5.5
OEx	15 Ft.	5.5
PE	18 Ft.	5.0
PEx	46 Ft.	4.5

The points OE, OEx, and PE have pH readings between 5.5 and 5.0 thus when one considers that PEx has a greater depth but a lower pH of 4.5 two things are possible. The Ohio shale has gotten much thicker at this place and/or there are vertical joints that are passing water faster than the limestone can increase the pH.

It is necessary to keep in mind that the conditions in the rocks above the cave are very much different than those within the cave. Specifically the partial pressure of carbon dioxide in the cave is very much less than in the rocks above. If the solution coming down has a load that will become supersaturated when the partial pressure of carbon dioxide is reduced to the level of the cave, calcite will be precipitated. If the solution load is less than saturated when the partial pressure of carbon dioxide is reduced to the level of the cave, calcite will be dissolved.

Currently the north arm of the cave is undergoing dissolution. There are solution pits in the concrete walkway and near CS6 there is a small drapery that shows a channel being cut into it. The edges are very sharp thus showing that the dissolution is contemporary. There was little evidence to indicate what the situation was in the west arm since it is relatively dry.

There is notning conclusive in the east arm but there are small pits eaten into the gravel on the floor. It is not clear whether the material was dissolved or displaced mechanically. The south arm shows no solution pits in the concrete walkway nor any obvious dissolution on the speleothems that were observed. The evidence would seem to indicate that deposition is going on.

There is insufficient evidence to determine what the exact relationships are between the thickness of the Ohio shale , the thickness of the Columbus limestone and the rate of infiltration of the solutions.

Acknowledgements

I should like to extend recognition to the following individuals for their contributions with respect to this research and paper:

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Suggestions for Further Research

To be able to say anything about the origin of the currents moving debris about the cave one would need to know the relative elevations of the various parts of the cave.

If these elevations could be plotted in turn with respect to the elevations on the surface it would be possible to get thicknesses for the Ohio shale, the soil and the Columbus limestone. With these and more numerous and precise pH readings a correlation could be established between thickness, rate of infiltration and the pH.

If the relative internal elevations were known and investigation of possible tilting of the area could be conducted. This could be done by examining stalagtites and stalagmites for non-vertical orientations and by examining water level horizons to determine if they are still level. Any tilting of the area would have an effect on the gradients within the cave and potentially on the movement of debris.

There are a few places where undisturbed debris deposits have been spared all but a minimum of trampling. These could be dug into and examined for grain size differences relative to depths to determine if any graded bedding was present. It would also be of value to investigate a debris cross section for other primary structures.

References

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6. Arthur L. Lange, (Introductory notes on the changing geometry of cave structures), Cave Studies, No.11, (1959) p.69-90

7. Arthur L. Lange, (Planes of Repose in Caves,) Cave Notes, Vols. IV-VI, (1962-64), p.41

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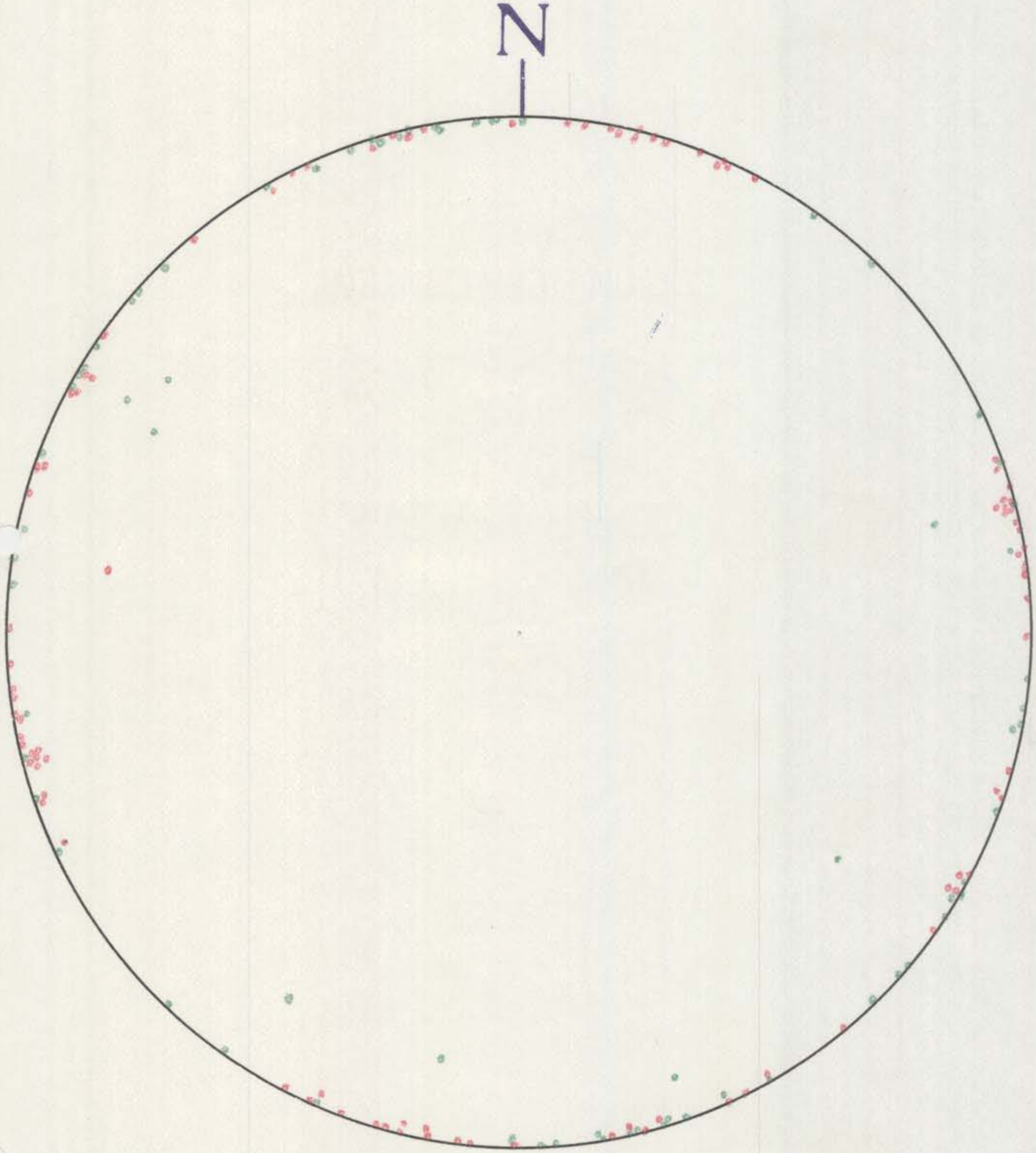
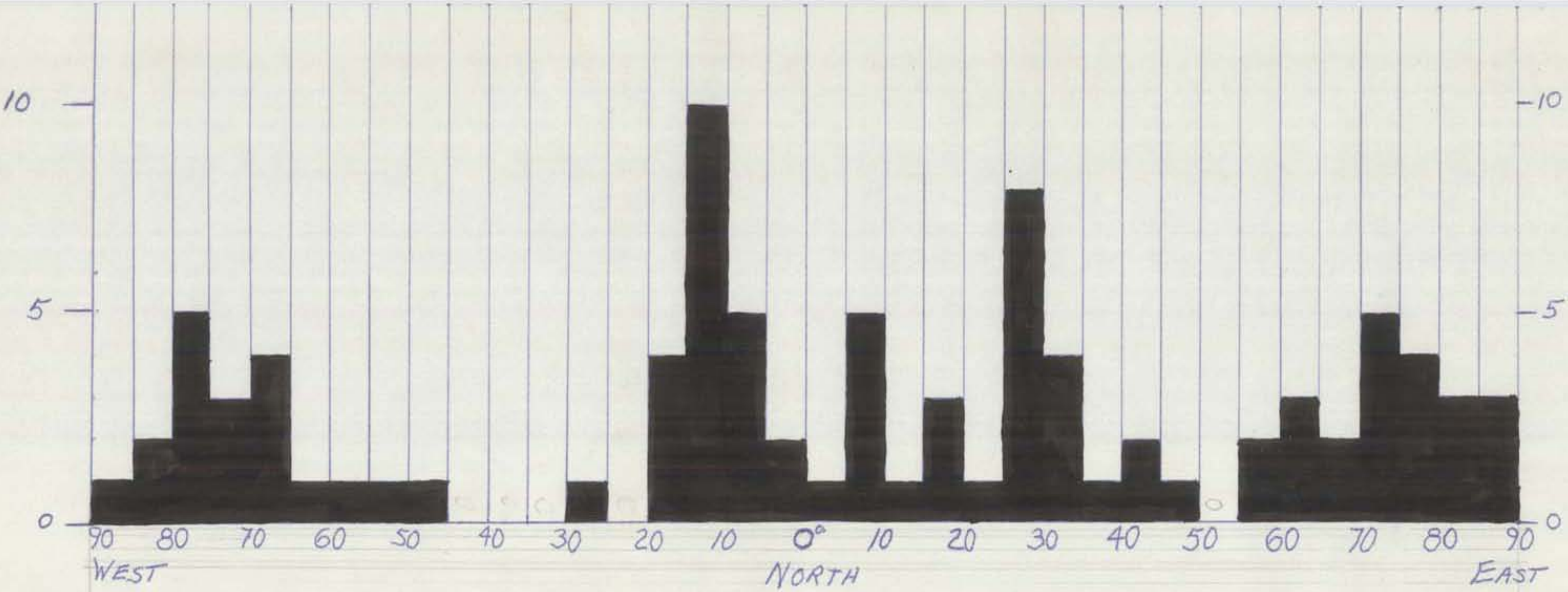
COMPOSITE



HISTOGRAM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NORTH
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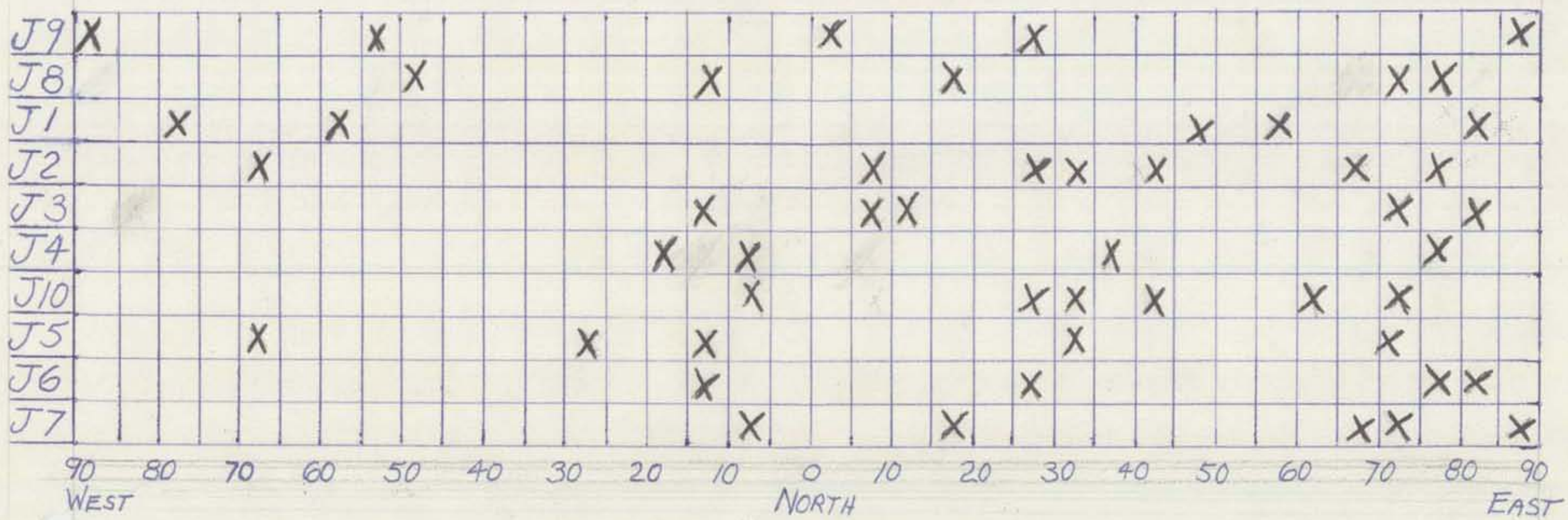
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J7
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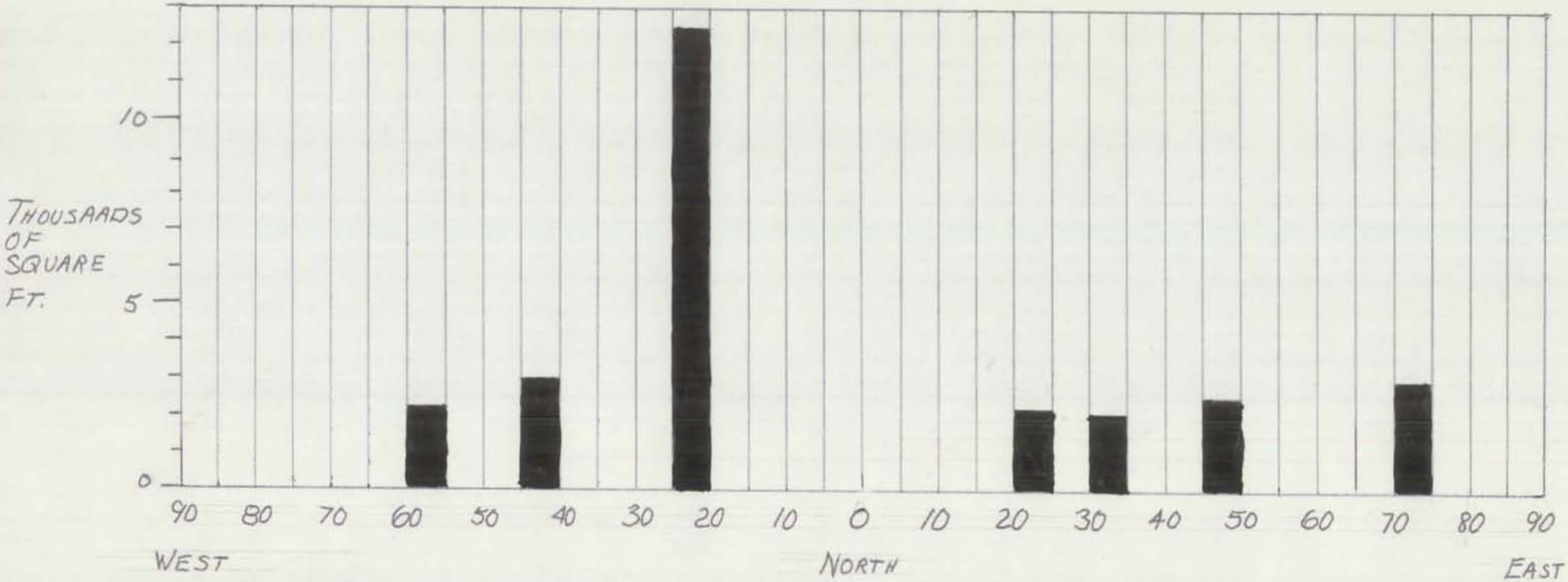
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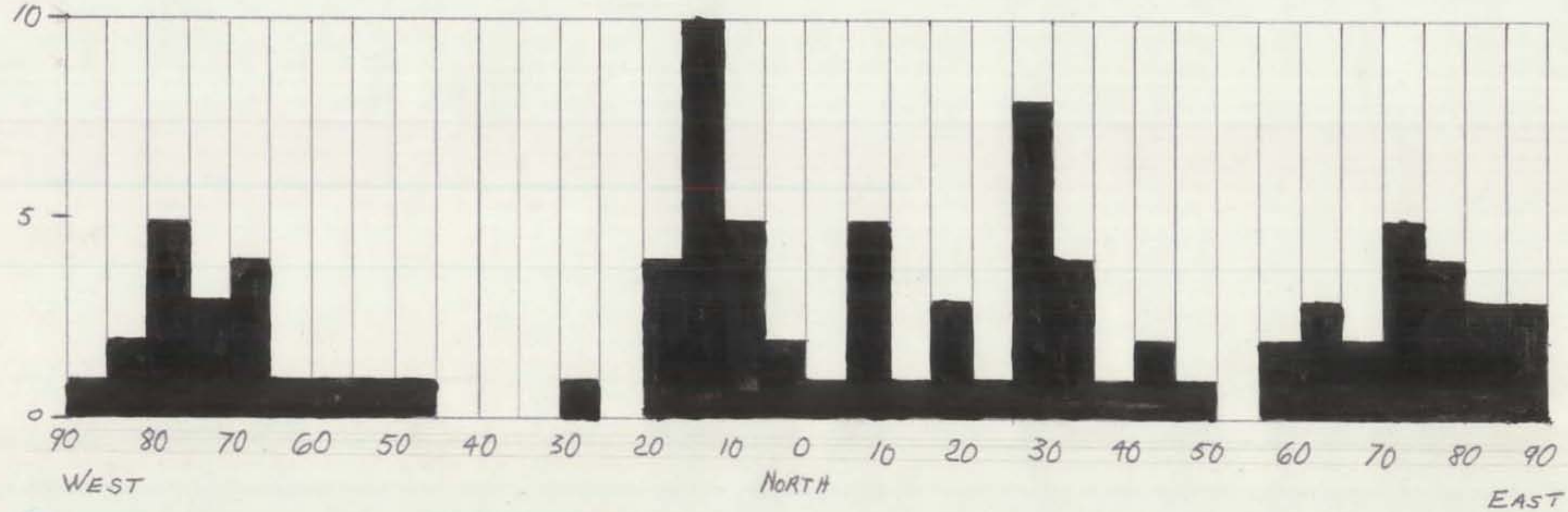
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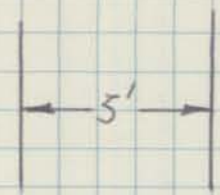
CROSS SECTIONS

SCALE 1 in.= 5' ft.



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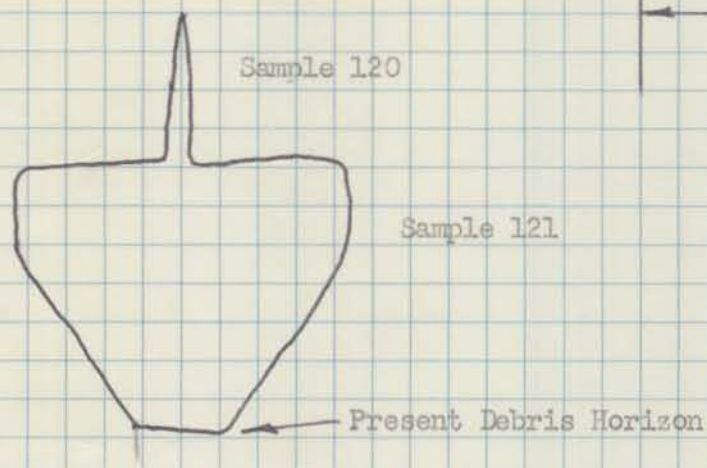

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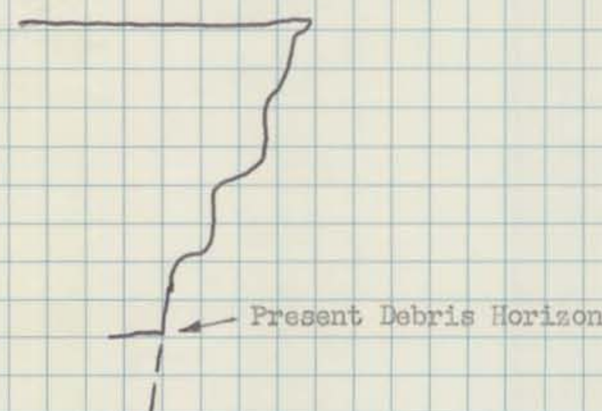
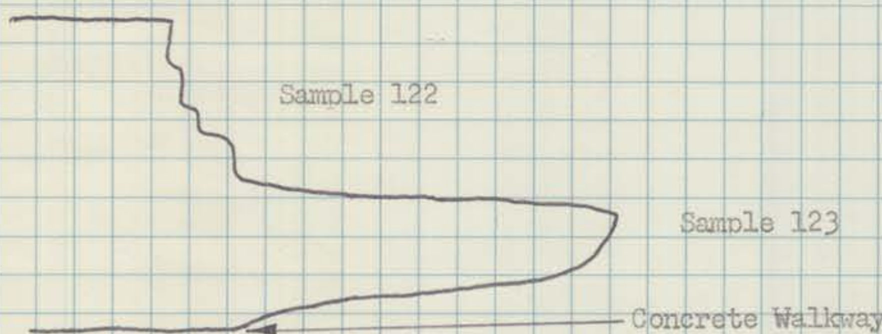


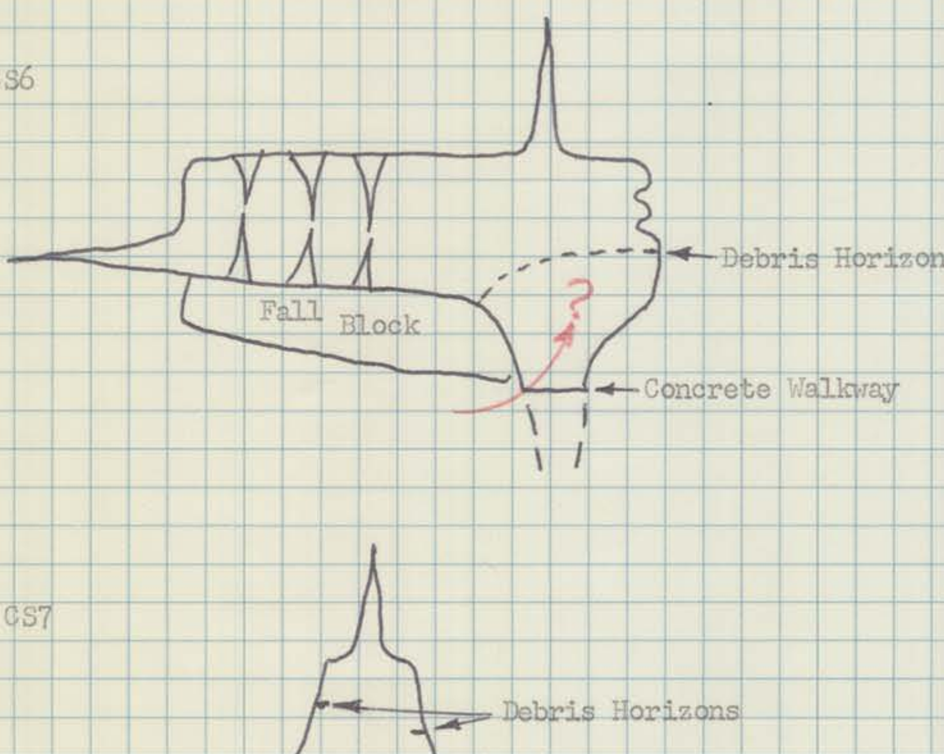
CS3

CS4

CS5



CS6



CS7